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Review

Potentiality of utilising natural textile materials for engineering composites applications

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ABSTRACT

This paper gives an overview of utilising natural textile materials as reinforcements for engineering composites applications. The definition and types of textile materials are addressed to provide readers a thoughtful view on the role of these materials in a structural composite system. Available material properties of natural textile and their composites are critically reviewed here. In general, these materials are categorised into fibre, yarn and fabric forms. The load bearing capacity of natural textile fibre reinforced polymer composites is governed by the quantity, alignment and dispersion properties of fibres. It has been found that the natural fibre reinforced composites are limited to use in low to medium load bearing applications. However, a limited research work has been performed to date and there is a significant gap between the high performance textile fabric and their use as reinforcement in fibre reinforced composite materials.

1. Introduction

Fibre, yarn and fabric are some of the reinforcement forms that are usually applied to fibre reinforced composites and these forms have been applied since before world-war II [1]. Carbon, glass, aramid, high modulus polyethylene, boron fibres are very common for composite reinforcement and they already gained a reputation due to their excellent properties such as lightweight, high strength to weight ratio and high thermal stability [2]. They are also known as high-performance reinforcement besides they dominate the aerospace, leisure, automotive, construction and sporting industries. Although these fibres/fabrics are excellent in terms of mechanical properties, they also possess some drawbacks such as high cost, non-recyclable, non-biodegradable, high health risk when inhaled, high-energy consumption and high density [3]. Some of the applications are not meant for structural or load bearing purposes, yet, utilising high-performance reinforcement for low and non-load bearing are not cost-effective and are over performance.

Recently, the search for new high performance materials at affordable costs has been expanded which is led from the growth of environmental awareness. The search has also focused on developing, creating and innovating eco-friendly materials [4–7]. Thus, new terms such as renewable, sustainable and biodegradable materials have appeared in the material scientists' vocabulary. The factor behind the increase of this search is due to the growing interests in reducing the environmental effects by polymers and composites, limited petroleum resources as it reduces the pressure of the dependence on petroleum products and the availability of the better understanding about the properties and morphologies of natural materials such as lignocellulosic fibres. Even in this bio-based composite material, the existence of textile material cannot be denied. Most of the reinforcements in composite material have close relation with textile materials and textile forms especially when the fibrous reinforcement is concerned. The classification of textile fibres itself shows the involvement of textile material in the bio-based composite field [8].

Earlier classification of textile material as reinforcement was established by Scardino [1]. He divided the textile structures or reinforcement forms into four categories; discontinuous chopped fibres, continuous filament yarns, simple fabrics (2-D) and advanced fabrics (3-D) systems. With this classification, he emphasized that textile composites can be tailored according to their end product and how the product will behave when subjected to force. Of course, his classification of textile material is applied for high-performance fibre such as glass, carbon and aramid but it can also be used for natural textile materials to some extent.

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Discontinuous chopped fibres are those that are randomly laid and bonded together through certain methods such as needling, spun-bonding, thermo-bonding and chemical-bonding (also known as nonwoven). In the case of continuous filament yarns, they are laid straight in one direction and usually pre-impregnated with resin and it is termed as unidirectional prepreg. Common method of manufacturing fabrics using high-performance fibres is interlacing or interloping of simple 2-D fabric. 2-D fabric is single plane structures manufactured by weaving or knitting. Woven fabric consists of interlacement of warp (length wise) and weft yarn (width wise). The 3-D fabrics are multi-plane structures and can be manufactured by weaving, warp knitting, braiding, nonwoven and other specially modified techniques.

When comparing all reinforcement forms, utilisation of traditional high-performance reinforcements is preferred in fabric form rather than fibre and yarn [1,9]. Fabric is easier to handle and could maintain its dimensional stability during the composite fabrication in comparison with other two forms. All fibres in the fabric are designed according to specific arrangements and alignments (also known as fabric structure) hence the fibres are interconnected with each other thus perform some kind of synergistic effect. Unlike fabric, yarn is formed by a group of aligned fibres and then some twisted until the direction of fibre becomes 10–80° in yarn longitudinal direction, yet, layering yarn for composite fabrication commonly does not connect them with each other [10,11]. Some yarn composites could surpass the strength of fabric composite in longitudinal direction; however, they are weaker in transverse or 45° direction [12]. Therefore, the performance of composite reinforced with yarn is depended on how the yarns are layered. Based from the discussion, to achieve the optimal performance of composite materials for specific applications, justification should be made regarding the selection of textile structures because some applications may not need very high strength or superior performances. However, when seeking for overall performances, fabric form is the best solution for this requirement.

This paper discusses the basic definition and hierarchical of textile and textile materials to establish the understanding on the existence of natural textile material in composite material. Since the main concern for this paper is the bio-based composites the discussions on the natural fibre properties are also conducted in order to relate their chemical composition and mechanical properties. Utilisation of natural textile material reinforced composite based on simple categorisation (fibre, yarn and fabric) is finally discussed to show the role of textile material in the materials. Some work has also been reviewed to show the current work in research and industry followed by the authors' opinion and suggestion related to the textile materials' utilisation.

2. Textile materials

2.1. Definition

The term 'textile' has a very broad meaning considering its evolvement over millennia. This term applies to product forms (fibre, yarn and fabric); either they are from natural or synthetic sources as well as the products derived from them. That includes all types of yarns or ropes (threads, cords, ropes and braided); all types of fabrics (woven, knitted and nonwoven); hosiery (knitwear and garments); household textiles, furnishing and upholstery; industrial and technical textiles (e.g. geotextiles, medical textiles and textile composites).

2.2. Fibres

Fibre is a basic unit in textile material and it can be clustered into two big groups which are natural and synthetic/man-made fibres [8]. Fig. 1 shows some types of textile fibres and its classification while Fig. 2 exhibits some example of fibres.

2.3. Yarns

A group of fibres with or without twist is called yarn and it has substantial length and relatively small cross-section. Monofilament is the yarn containing only one fibre for example, nylon. Untwisted, thick yarns are termed tows and this term is usually applied for high-performance yarn such as glass, aramid and carbon. In twisted yarns, the friction resulting from twist consolidates fibres. A twist is introduced to a continuous filament yarn by twisting. For a twisted yarn made of staple fibres, the process is called spinning and involves a long chain of preparatory operations. There is different yarn spinning processes (ring spinning, open-end spinning, friction spinning) leading to yarns with distinctive internal distributions of fibres. Fig. 2 shows some example of yarns.

2.4. Fabrics

Next transformation of textile fibres after being a yarn is fabrics. Three distinctive common fabric types are woven, knitted and nonwoven fabrics produced by weaving, knitting and various non-woven processes respectively. Fig. 3 shows different types of fabric structure. Woven fabrics generally consist of two sets of yarns that are interlaced and lie at right angles to each other. The threads that run along the length of the fabric are known as warp ends whilst the threads run from selvedge to selvedge, that is from one side to the other side of the fabric, are weft picks. Frequently, they are simply referred as ends and picks [14].

Knitted fabric consists of interloping yarns either weft (weft knitting) or warp (warp knitting) directions. Warp knitting is a method of manufacturing a fabric by standard knitting means, in which the loops made from each warp are formed substantially along the length of the fabric while weft knitting is a method of producing a fabric by normal knitting means, in which the loops by each weft thread are formed considerably across the width of the fabric [15].

A nonwoven is a textile structure produced by the bonding or interlocking of fibres, or both, accomplished by mechanical, chemical, thermal or solvent means and combinations thereof. It has to be admitted that this definition is not very precise, but it has been chosen because it includes many important fabrics which most people regard as nonwovens. One of the major advantages of nonwoven manufacture is that it is generally done in one continuous process directly from the raw material to the finished fabric, although there are some exceptions to this [16].

Fabric types mentioned are the usual single plane structures also known as 2-D fabrics in which high-performance fibres are available. However beyond that, fabric in multi-plane structures or 3-D fabrics can as well be manufactured by weaving, warp knitting, braiding, non-woven and other specially modified techniques. The various techniques on fabric manufacturing allow more flexibility on tailoring the textile material which could be used in diverse of applications.

2.5. Textile materials classification and concept

The broad definition of textile and various of textile material have allowed them not only in apparel and garment but also in technical industry such as automotive, aeronautic, infrastructure and composite. Lomov et al. [10] in their work concluded that the definition introduces three important notions. First, it states that textile are fibrous materials made from fibres which are characterised by flexibility, fineness and high ratio of length (usually greater than 100 degree of polymerisation). Fibre diameters for